THE EFFECT OF PRESENTATION RATE ON THE COMPREHENSION AND RECALL OF SPEECH AFTER ANTERIOR TEMPORAL-LOBE RESECTION

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M.Sc Psychology

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Abstract

Abnormally slow processing of language may be a factor contributing to the poor verbal memory seen in many patients with lesions of the anterior temporal region in the left hemisphere. This possibility was examined by comparing the performance of 12 patients with left temporal-lobe resections (LT), 10 patients with similar lesions in the right hemisphere (RT) and 13 normal control (NC) subjects on a lexical-decision task, a sentence-plausibility-judgement task, and a story-recall task. Stimuli were presented aurally, and, in the latter two tasks, at 5 different speech rates ranging from 125 words per minute (wpm) to 325 wpm. Recall of stories by LT subjects was not abnormally sensitive to the effect of increasing rate, although it was inferior to that by NC subjects at all speeds. LT patients were also impaired at judging the lexicality of words and nonwords presented aurally but not visually (Frisk and Milner, 1991), suggesting that the left anterior temporal region plays a special role in the processing of speech sounds.

M.Sc Psychologie

Ingrid S. Johnsrude

L'EFFET DE LA VITESSE DE PRESENTATION SUR LA COMPREHENSION ET LE RAPPEL DU DISCOURS APRES RESECTION DU LOBE TEMPORAL ANTERIEUR

Resumé

Un ralentissement anormal dans le traitement du langage peut être un facteur qui contribue au déficit de mémoire démontré chez de nombreux patients ayant une lésion dans la région temporale antérieure de l'hémisphère gauche. On a examiné cette possibilité en comparant la facilité avec laquelle 12 patients avec résections du lobe temporal gauche (TG), 10 patients avec des lésions similaires dans l'hémisphère droit, et 13 sujets témoins se sont acquités de décisions lexicales, ont jugé la plausibilité de phrases, et ont rappelé des histoires courtes. Les stimuli ont été présentés auditivement, et, dans les deux dernières tâches, à 5 vitesses différentes variant de 125 mots par minute à 325 mots par minute. Le rappel des histoires par les sujets TG n'a pas été anormalement affecté par l'augmentation de la vitesse de la parole, bien qu'il fût inférieur à celui des sujets témoins à toutes les vitesses. La performance des sujets TG a été également affecteé lors des tâches de jugement de la légitimité de mots et de faux-mots, qui avaient été presentés auditivement mais pas visuellement (Frisk et Milner, 1991). Ceci suggère que le lobe temporal antérieur gauche joue un rôle particulier dans le traitement des sons du langage.

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Much of the evidence for the role of the temporal lobes in memory has come from studies of the effects of lesions in human subjects who have undergone unilateral anterior temporal-lobe resection for the relief of pharmacologically intractable epilepsy. For people with focal epilepsy who are not responding well to anti-convulsant medication, resection of the epileptogenic brain tissue is often an effective means of controlling their seizures, provided that the focus of epileptogenic discharge is relatively circumscribed. At the Montreal Neurological Hospital, the removal in cases of temporal-lobe epilepsy generally includes the anterior temporal neocortex, the uncus, and the amygdaloid complex. In addition, the resection often encompasses some amount of the hippocampus and parahippocampal gyrus. As a result of the temporal-lobe resection, most patients show an homonymous upper-quadrant defect in the visual field contralateral to the side of the excision, owing to interruption of the optic radiations. Although I.Q. ratings tend to be slightly depressed immediately after surgery, there is no long-term reduction from the pre-surgical level; in fact, I.Q. ratings may go up if the operation has resulted in good seizure control (Milner, 1985). Likewise, there appear to be no long-term impairments in immediate-memory span (Corsi, 1972; Penfield & Milner, 1958) or in working memory capacity (Frisk & Milner, 1990a), so that it is within a context of preserved function that one sees the persistent, material-specific impairments caused by unilateral anterior temporal-lobe damage. A poor verbal memory is the most evident impairment after left-sided removal (Blakemore & Falconer, 1967; Frisk & Milner, 1990b; Meyer, 1959; Meyer & Yates, 1955; Milner, 1958). In the case of a right-sided removal, visual perceptual deficits (Kimura, 1963; Lansdell, 1968; Meier & French, 1965; Milner, 1958) and impairments in the discrimination of

melodies (Samson & Zatorre, 1988; Zatorre, 1985) are often observed, as are impaired memory for visual patterns (Kimura, 1963; Milner, 1968; Taylor, 1969; Warrington & James, 1967), and spatial arrangements (Corkin, 1965; Corsi, 1972; Milner, 1965; Smith & Milner, 1981)..

Left anterior temporal-lobe excision results in a deficient ability to learn and remember verbal material, regardless of whether retention is assessed by free recall (Frisk & Milner, 1990b; Meyer & Yates, 1955; Milner, 1958, 1967; Rains, 1981; Read, 1981a), recognition (Blakemore & Falconer, 1967; Frisk & Milner, 1990b; Meyer, 1959; Rains, 1981), or savings methods (Meyer & Yates,.1955), and regardless of whether the material is presented in the visual or auditory mode (Milner, 1967). Patients with such lesions have trouble with the initial learning of verbal paired associates (Blakemore & Falconer, 1967; Meyer, 1959; Meyer & Yates, 1955; Milner, 1958) and the definitions of unfamiliar words (Meyer & Yates, 1955; Meyer, 1959), and their retention of this material over a delay is also poor (Meyer & Yates, 1955; Milner, 1958). The impoverished recall of short prose passages, four or five sentences in length, remains the most conspicuous deficit exhibited by such patients. Their recall of these passages is unusually scanty immediately after presentation (Milner; 1958; Milner, 1967; Frisk & Milner, 1990b; Frisk & Milner, 1991), with further loss evident after a delay (Milner, 1958; 1967). Even one or more years after operation, when these patients are asked to recall stories that they had heard about one and a half hours earlier, they can typically recall only 40 percent as much as normal control subjects (Milner, 1958). Like control subjects, these patients tend to remember a higher proportion of important ideas and a smaller proportion of details (Frisk & Milner, 1990b; Prevey, Delaney, & Mattson, 1988), but they have a greater tendency than control

subjects to produce major distortions in the story (Prevey, Delaney, & Mattson, 1988). Milner (1958) has reported that, in fact, these patients recall the stories in a very fragmented manner, and in some cases, the recalled material is so disordered that the original story line is no longer evident.

It now seems highly probable that difficulty with storage is the primary cause of the verbal memory deficit in patients with left anterior temporal-lobe removals. These patients seem to forget things abnormally quickly, in that their recall of verbal material is more sensitive to a delay interposed between learning and recall than is that by normal subjects and non-aphasic patients with lesions in other cortical areas (Milner,1958; Read, 1981a). Even if the material to be remembered is initially learned to the same criterion by patients with left temporal-lobe lesions and normal subjects, recall by the patients after a 20-minute delay is significantly impoverished (Frisk & Milner, 1990b). Nevertheless, impaired storage may not be the only cause of memory defects in these patients. Difficulties with both retrieval and encoding are putative contributing factors, and I shall concentrate on the possible contribution of encoding impairments.

Difficulties with encoding information, such as the poor use of organizing strategies, are most evident in patients with lesions of the left or right frontal lobe (Incisa della Rocchetta, 1986). Nevertheless, there are several indications in the literature that encoding impairments are also present, albeit to a lesser degree, in patients with left-temporal lobe removals and deficient verbal memories. Thus, it has been observed that these patients are less likely than control subjects to make use of active learning strategies such as notetaking, underlining or subvocalization (Prevey, Delaney, & Mattson, 1988). In addition, there have been several

studies indicating that they are worse than normal subjects at assimilating and making use of information under time pressure. The first indications of this come from an apparent discrepancy in the findings of Meyer (1959) and Milner (1967) for the learning of visually presented paired-associate words by patients with anterior left temporal removals. Meyer (1959) assessed the ability of patients with anterior left temporal removals to learn lists of paired-associate words, presented both aurally and visually, to a specific criterion. Finding that his patients were impaired at only the auditory version of the task, he concluded that the verbal deficits observed in such patients were specifically auditory in nature. Milner (1967) demonstrated successfully that such patients are impaired at the associative learning of visual word pairs, contradicting the findings of Meyer (1959). A crucial difference between the two experiments may have been that whereas Meyer (1959) permitted subjects to read the associates at their own pace, Milner (1967) paced her subjects, so that the conditions of the visual version were more similar to those of the auditory version. Discussing this discrepancy, Blakemore & Falconer (1967) suggested that "the rate of presentation of the materials to be learned may be a significant variable" (p 364). In addition, Meyer (1959) anecdotally mentions that several of his patients complained of difficulties in following fast (but not slow) conversation. More recently, Wilkins and Moscovitch (1978) showed that patients with left temporal-lobe lesions were mildly impaired relative to normal subjects on a paced-naming test (Rochford & Williams, 1962) in which they were required to name objects rapidly and classify them as living or man-made. Read (1981b) has shown that patients with such excisions are impaired at solving deductive-reasoning problems in which they are required to integrate rapidly the information conveyed in two or

three statements (For example, 'A is taller than B. B is taller than C. Who is tallest?). Finally, more indirect evidence comes from Milner (1967), who found that these patients were slower than normal control subjects and those with right anterior temporal-lobe excisions at a speed of reading task, in which subjects must read short paragraphs quickly, while comprehending them well enough to identify the anomalous word. What the three tasks described above have in common is that for successful performance, the subject must be able to assimilate and process verbal information quickly. It is possible that patients with excisions from the left-temporal lobe are no longer able to process verbal information as rapidly as normal subjects, and this deficit could contribute to their manifestly poor memory for this type of material.

The hypothesis, first suggested by Blakemore & Falconer (1967), that left-temporal excision slows the rate at which verbal information can be processed, was examined by Frisk and Milner (1991) for verbal material presented visually. Using a rapid serial visual presentation (RSVP) procedure, these investigators flashed sentences, stories, and single words at the subject's fixation point on a computer screen at either a slow (2 words per second [wps]), moderate (5 wps), or fast (8 wps) reading rate, in order to examine the abilities of patients with left and right temporal-lobe excisions and normal control subjects to process these materials. Comprehension of the single word items was assessed by requiring subjects to decide whether each was a real English word. They assessed comprehension of the sentences by requiring subjects to judge their plausibility, and story comprehesion was assessed by requiring subjects to judge the correctness of several statements about each story. It has been shown that comprehension and retention by normal subjects of short prose

passages presented in this manner declines as presentation rate increases from slow (4 wps) to fast (8-12 wps) (Potter, Kroll, & Harris, 1980; Juola, Ward, & McNamara, 1982). Frisk and Milner (1991) reasoned that if patients with left-temporal excisions cannot process visually presented verbal material as quickly as normal subjects, then their recall of the short prose passages should be disproportionately affected by the increase in presentation rate. The lexical-decision task and the sentence-plausibility-judgement task were included in order to rule out the possibility that any deficits in story recall observed in the left temporal-lobe group were secondary to impaired processing of single words or sentences (Frisk & Milner, 1991).

The results obtained by Frisk and Milner (1991) did not support the hypothesis that left temporal excisions affect the rate at which visually presented verbal material can be processed. Although error rate increased with increasing rate of presentation, it did so equally for all groups. Therefore, although patients with left temporal excisions tended to make more errors than normal control subjects when judging the truth or falsity of statements about the short passages, they showed an equal impairment at all presentation rates, and were therefore not differentially affected by the increase in rate of presentation.

The results described above do not completely rule out the possibility that patients with left temporal excisions process language more slowly than normal subjects. The possibility remains that an effect would be obtained if the material were presented aurally (instead of visually) at increasingly faster rates. The results of several studies indicate that the left anterior temporal neocortex may play a particular role in the auditory processing of language (Milner, 1985; Rains,1981; Read, 1981a; Zatorre, 1989)

Zatorre (1989) has reported that whereas normal control subjects and patients with resections of the right anterior temporal region are able to identify systematically distorted versions of familiar melodies, patients with excisions from the anterior region of the left temporal lobe are significantly impaired. Since all the stimulus melodies were closely associated with lyrics, and it is only through access to the lyrics, presumably, that the melody could be named, this finding may indicate that such patients have difficulty accessing language via auditory channels.

Rains (1981) examined the effect of depth of processing (Craik & Lockhart, 1972) on the retention of word stimuli by normal control subjects and patients with either right or left temporal excisions. He first required his subjects to decide whether a particular word was written in capital letters, whether it rhymed with another word, or whether it belonged to a specific category, thus ensuring that they were processing the words for either their structural, phonemic, or semantic characteristics, respectively. Immediately after presentation, retention was assessed using free recall and recognition methods. He found that, for all groups, free recall and recognition were best for words that had been processed semantically and poorest for words that had been processed for their physical features, thus replicating the results found by Craik and Tulving (1975) for normal subjects. Furthermore, the magnitude of the difference in recall after these two types of processing was the same for all groups. There was, however, a difference between groups in the facilitative effect of phonemic processing over structural processing on recall. Rains (1981) found that, in contrast to recall by control subjects and patients with right temporal removals, recall by patients with left temporal excisions was not helped by requiring

phonemic processing. He interpreted this to mean that the left anterior temporal region plays a role in the evocation of the sounds of words.

A similar result was obtained by Read (1981a) who required control subjects and those with unilateral temporal-lobe excisions to generate supraspan word lists according to one of two rules (either semantically, where the subjects were given a synonym and the first letter of the target word, or phonemically, where they were given a rhyming word and the first letter). Immediately after the words were generated, Read examined how the two rules differentially influenced recall of the target words. He found that even though patients with left temporal-lobe excisions sparing most or all of the hippocampus recalled as many semantically generated words as did control subjects, their recall of words generated on the basis of rhymes was markedly inferior. As this result was obtained for patients in whom the hippocampus had been largely or entirely spared, it was suggested that the left anterior temporal neocortex plays a role in processing and retaining the sounds of recently heard words (Milner, 1985).

In addition, there is evidence from other sources pointing specifically to a role for the left anterior temporal neocortex in mnemonic functions. Burke and her colleagues (Burke and Nolan, 1988; Burke, Nolan & Staunton, 1991) used a forced-choice recognition procedure to assess memory for abstract and concrete words, and they found that, relative to normal control subjects and patients with a right temporal neocorticectomy, patients with a left temporal neocorticectomy were significantly impaired. Furthermore, electrical stimulation at several sites on the surface of the superior and middle temporal gyri in the left hemisphere appears to disrupt the recall of the names of objects portrayed in representational drawings, if the stimulation is administered during the presentation of the drawing, or

during the delay between presentation and recall (Ojemann & Dodrill, 1985). Finally, Ojemann and his colleagues (Ojemann, Creutzfeldt, Lettich & Haglund, 1988) also report the existence of various sites throughout the lateral left temporal neocortex that exhibit changes in neuronal activity during the delay period and during recall, presumably attributable to storage and retrieval functions.

The Present Investigation

The purpose of this study was to examine the possibility that left temporal neocortical excisions may interfere with the processing, and hence with the recall of spoken language. A number of experiements in normal subjects have demonstrated that speech comprehension declines rapidly as the rate of presentation increases (Fairbanks, Guttman, & Miron, 1957; Foulke & Sticht, 1969; Heiman, Leo, Leighbody, & Bowler, 1986). Although it has never been explicitly examined, subsequent recall of information presumably depends in part on how well it was initially comprehended, so that recall would worsen as comprehension declines. Foulke and Sticht (1969) report that comprehension declines moderately as the speech rate increases from 175 to 275 wpm, and then declines more rapidly as speech rate increases beyond 275 wpm. Even though these authors used an artificial means of speech acceleration, this decline in comprehension cannot be attributed to distortion in the speech signal since word intelligibility (the accuracy with which a word can be repeated after it has been heard in isolation) does not drop below 90% for the signals in question (Garvey, 1953). Instead, the authors attribute the decline in comprehension to a processing overload in short-term memory (Foulke & Sticht, 1969).

Studies conducted on populations in the midwestern United States have shown that a speech rate of about 165 words per minute (wpm) is the most comfortable for normal adults to listen to (Hutton, 1954), and that the average rate at which people read aloud is about 175 wpm (Johnson, Darley, & Spriestersbach, 1963; Foulke, 1968). Others have found that rates below 139 wpm and above 189 wpm are judged to be 'slow' and 'fast' respectively (Franke, 1939). Although these values are likely to vary from region to region, they are probably valid for the anglophone patients seen at the Montreal Neurological Hospital.

In the present study, sentences and stories were presented aurally at slow (125 wpm) normal (175 wpm) and fast (225, 275, and 325 wpm) rates, in order to find out whether patients with left anterior temporal-lobe excisions are unusually sensitive to the processing load of normal and accelerated speech. Because it seemed important to make the test stimuli as realistic as possible, only rates of speech that could conceivably be encountered in real life were used, and speech was not compressed mechanically. If left anterior temporal lobectomy does slow the rate at which speech can be processed, one would expect the comprehension and recall of spoken material by patients with such lesions to be facilitated by a slow rate of presentation, and increasingly hampered as the rate of presentation increases. In contrast, comprehension by patients with right temporal-lobe excisions and by normal control subjects should not begin to decline until the presentation rate surpasses that of normal speech.

Method

Subjects

Each of the 22 patients who participated in this experiment had undergone a unilateral anterior temporal lobectomy at the Montreal Neurological Hospital. These operations had been performed to relieve pharmacologically intractable epilepsy. In the majority of cases, the cause of the seizures was focal cerebral atrophy dating from birth or early life, although 4 cases of indolent tumour and 1 case of head trauma were also included. Patients with diffuse cerebral damage or malignant tumours were excluded, as were those with evidence of bilateral independent electrographic abnormalities. In addition, patients with language represented either wholly or partially in the right cerebral hemisphere, as determined by preoperative sodium Amytal[1] studies (Branch, Milner, & Rasmussen, 1964; Wada & Rasmussen, 1960), were excluded from the experiment, as were those patients obtaining Full Scale IQ ratings below 80 on the Wechsler Adult Intelligence Scale - Revised (WAIS-R). Because the test material was in English, all patients tested were required to be either native speakers of English or fluently bilingual individuals who had received all of their formal education in English.

Handedness in all patients was assessed using a modified version of the Handedness Questionnaire (Crovitz and Zener, 1962) . The verbal memory of all patients was assessed within a day of their participation in this study, by obtaining the free recall of paired-associate words and short prose passages both immediately after presentation, and then after a delay of about 90 minutes. All test materials were taken from the Wechsler Memory

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[1] Sodium amobarbital, Eli Lilly and Company, Indianapolis, Indiana, U.S.A.

Scales, Form I or II (Wechsler, 1945), with the exception of the Form I stories, which had been slightly modified to bring them up to date.

The patients were assigned either to the left temporal-lobe (LT) group or to the right temporal-lobe (RT) group, according to the side of the excision. Thirteen normal control (NC) subjects were also tested, making three groups in total.

Information regarding the sex, age and educational level in each group is given in Table 1. Table 2 presents information about the Full-Scale, Verbal and Performance I.Q. ratings of the patients, assessed using the WAIS-R (Wechsler, 1981). and Table 3 presents the mean scores obtained by each patient group on immediate and delayed free recall of the short prose passages, and on cued recall of the paired-associate words. I.Q ratings were not obtained for the normal control subjects, and their verbal memory was not formally assessed.

Left-temporal lobe group. Each of the 12 patients in this group had undergone a left anterior temporal-lobe resection, which always included the anterior temporal neocortex, the uncus and amygdala, and which in 10 patients encroached upon the hippocampus and parahippocampal gyrus. In 4 patients, hippocampal resection was limited to the pes of the hippocampus; in 5 patients the removal included up to 2.5 cm of the body of the hippocampus; and in 1 patient, 3 cm of the hippocampus was excised. The mean extent of the removal along the Sylvian fissure was 4.3 cm, and along the base of the temporal lobe it was 4.8 cm. The primary auditory cortex (transverse gyri of Heschl) was spared in all LT patients. An excision representative of those from the left temporal lobe is displayed on the left side of Figure 1. Five of the patients in the LT group were seen 2 weeks after surgery and the remainder one or more years after their operation.

Table 1

Subjects

Group	Sex		Age (years)		Education (years)	
	M	F	Mean	Range	Mean	Range
Left temporal	8	4	28	19-38	14	11-17
Right temporal	6	4	29	12-41	13	7-17
Normal control	7	6	31	20-48	14	11-17

Table 2

Wechsler Full-Scale I. Q.Verbal I.Q. and Performance I.Q. in the Temporal-Lobe Groups

	Full-Scale I.Q..		Verbal I.Q.		Performance I.Q.	
Group	Mean	Range	Mean	Range	Mean	Range
Left temporal	98	88-127	94	80-129	105	87-132
Right temporal	106	90-127	104	89-122	107	92-133

Table 3

Mean Scores obtained by Patients in Temporal-Lobe Groups on Tests of Verbal Memory

	Immediate recall				Delayed recall			
	Stories		Paired associates		Stories		Paired associates	
Group	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Left temporal	7.5	4.5-12.0	11.0	5.5-16.5	5.0	2.0-9.0	6.0	2.0-9.0
Right temporal	10.5	8.0-13.0	15.5	9.0-21.0	7.5	2.5-10.5	8.5	5.0-10.0

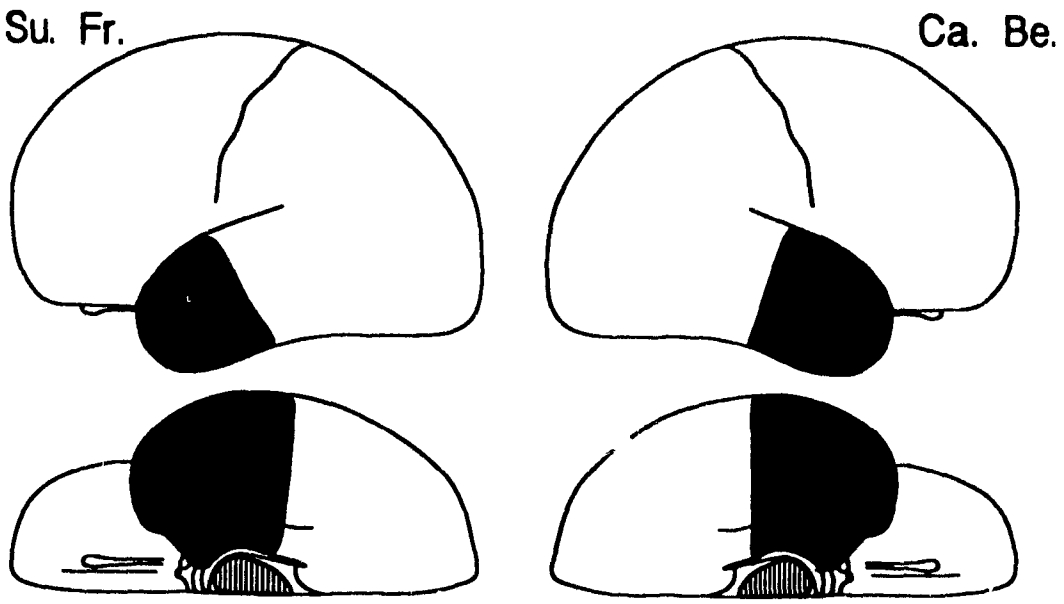

Figure 1. Brain maps based on the surgeon's drawings at the time of operation and on measurements given in the operation report, showing (in black) the estimated lateral and mesial extent of typical excisions from the left and right temporal lobes. The patient Su. Fr. belonged to the LT group, and Ca. Be. belonged to the RT group. Both of these removals happened to include a large portion (more than 1.5 cm) of the hippocampal formation.

Right-temporal lobe group. Ten patients (6 right-handed, 3 left-handed, and one of mixed handedness) had excisions from the right temporal lobe (RT), similar to those on the left side. The mean extent of the removal was 5.0 cm along the Sylvian fissure, and 5.6 cm along the base of the temporal lobe (see Figure 1). Resection in one patient included part of Heschl's gyri, and nine of the patients had excisions of varying extent from the hippocampus. The hippocampal resection in 2 patients was limited to the pes (1.5 cm); 6 removals included up to 2.5 cm of the hippocampus; and 1 patient had had more than 2.5 cm of the hippocampus removed. An excision representative of those from the right temporal lobe is displayed on the right side of Figure 1. Two of these patients were seen 2 weeks after surgery, one 4 months after surgery, and the remainder one or more years after their operation.

Normal control group. The 13 normal control subjects (all right-handed) were matched as far as possible to the patients with respect to sex, age, and level of education. Five of these subjects were employees of the hospital, 5 were relatives of the patients, and 3 were acquaintances of the author. No subject had any history of neurological illness or trauma, and all were native speakers of English.

Group comparisons. The three groups did not differ significantly with respect to age (F (2,32) = 0.81, $p > .05$), or years of education (F (2,32) = 0.75, $p > .05$), and there was no significant difference between the two patient groups with respect to Full Scale I.Q. (F (1,20) = 1.60, $p > .05$). There was, however, a significant difference between patient groups with respect to the size of the neocortical excision. The excisions were larger in RT patients than in LT patients, both along the Sylvian fissure (F (1,20) =

15.68, $p < .005$) and along the base of the temporal lobe ($F(1,20) = 15.50$, $p < .005$).

Tasks and Procedure

All subjects performed a lexical-decision task, a sentence-plausibility-judgement task, and a story-memory task, in the order in which the tasks are described below. Materials presented in all practice trials are listed in Table A of the Appendix, and the materials presented in the three experimental tasks are listed in Tables B, C, and D, respectively.

Lexical-decision task. The 48 items making up this task were monosyllabic utterances of four or five letters (24 words and 24 nonwords), selected from those used by Frisk and Milner (Frisk, 1988; Frisk & Milner, 1991). The experimenter's own voice was used for all the stimuli in this and the following two conditions. The signals to be digitized were fed through a DFRM high-bias filter and a TASCAM M-06 amplifier, and the stimuli were digitized at 16000 samples per second using MITSYN software running on a Compaq 386/ Model 120 with a Data Translation analogue subsystem. The stimuli were presented to the subjects through earphones (Sennheiser) via the amplifier and the computer, using MAPLE software.

The subjects were told that they were going to hear several words and nonwords, one at a time, in random order. If they thought that what they heard was a real English word, they should hit the key marked "T" (for true) with their dominant hand. They were told to hit the key marked 'F' (for false) with their nondominant hand if they thought that the stimulus they had heard was not a real word. Counterbalancing of hands was not carried out because Frisk and Milner (Frisk, 1988; Frisk & Milner, 1991) had found in pilot testing that, when subjects were required to use their nondominant hand for a 'true' response, many more errors were made than

when the dominant hand was used. Four practice trials, two with words and two with nonwords, were presented first to familiarize the subjects with the task.

The subject's response and the latency to respond were recorded for each stimulus. The latency from the onset of the stimulus to the onset of the subject's response was recorded by the computer. The intertrial interval (measured from the instant of the subject's response to the onset of the next stimulus) was about 500 milliseconds (ms).

Sentence-plausibility-judgement task. There were 90 sentences, each containing from 7 to 15 words and from 9 to 20 syllables. Fifty-four of these sentences were taken from Frisk and Milner (Frisk, 1988; Frisk & Milner, 1991), and 36 were new. Half of the sentences were plausible ('The glass slipped from Larry's hand and fell to the floor') and half were more improbable ('Playing the guitar is a popular pastime for young dogs.'). The anomalous word in each of the implausible sentences was always located near the end, to ensure that the subject attended to the entire sentence before responding. The sentences, matched for number of words and syllables, were pseudorandomly assigned to five lists of 18 sentences (nine plausible and nine improbable).

The sentences in a particular list were all digitized at the same speech rate, and each of the five lists was assigned to different rate. The rates used were approximately 125 wpm (162 syllables per minute (spm)), 175 wpm (236 spm), 225 wpm (286 spm), 275 wpm (374 spm), and 325 wpm (445 spm). In order to digitize each sentence at the correct rate, I looked at the number of words and syllables in the sentence, and used these to obtain two estimates of how long it should take to utter the sentence (one based on words per minute and one based on syllables per minute). I then altered my

speech rate so that it took an amount of time intermediate between the two estimates to recite the sentence.

The five lists were presented in a random order, and, within each list, the 18 sentences were also presented randomly. The subjects were told that they should hit the key marked 'T' with their dominant hand if they thought that the sentence they had heard was plausible, and to hit the key marked 'F' with their nondominant hand if they thought that the sentence was nonsensical. They were informed that there would be five 'batches' of sentences, each recited at a different speed, but that their task was the same regardless of the rate of recitation. Four practice trials, composed of two plausible sentences and two nonsensical sentences, and digitized at the middle speech rate, were presented first to familiarize the subjects with the task. As in the first condition, responses and latencies (timed from the onset of the stimulus to the onset of the subject's response) were recorded, and the intertrial interval (measured from the instant of the subject's response to the onset of the next stimulus) was about 500 milliseconds.

Story-memory task. Twenty-five stories, each followed by four statements (either true or false) about the content of the story, were used. Fifteen stories were taken from those used by Frisk and Milner (Frisk, 1988; Frisk & Milner, 1991). The remaining 10 stories were pretested on 20 normal control subjects in the following way. The story was recited to the subjects at an average rate (about 225 wpm), and then the subjects were required to decide whether each of the four statements following the story was true or false. Following the criterion set by Frisk and Milner (Frisk, 1988; Frisk & Milner, 1991) to ensure that a statement was not overly difficult, any statements that were not answered correctly by at least 16 of the 20 normal control subjects were revised and pretested again. Five

stories, with accompanying statements, were pseudorandomly assigned to each of the five stimulus lists The lists were matched as closely as possible for the number of sentences, words, and syllables in the stories, and each list contained an equal number of true and false statements.

The stories in any particular list were digitized at the same speech rate; each list of stories at a different rate. The rates used for the stories were the same as those used in the sentence condition, and the same method was used to determine how long it should take to recite the story to be digitized. All statements were digitized at the same rate: about 175 wpm.

Subjects were presented with the lists in a pseudorandom order, with the restriction that the list at the fastest speed was never presented first. Within each list, the stories were presented randomly, as were the statements after each story.

The instructions to the subjects were:

> Now you will hear a series of stories, which will be presented one at a time. After each story, you will hear four statements about that story, one at a time. Your task is to decide whether each statement is true or false, based on the information that was contained in the story. If you wish to hear the statement again before deciding, press the space bar. If you decide that the statement is true, press the key marked 'T'. If you decide that the statement is false, press the key marked 'F'. Unlike the statements, the stories cannot be played more than once. The stories will be told to you at different speeds, but your task is the same whatever the speed.

The subjects were permitted to hear each statement as many times as they wished in order to rule out the possibility of errors

resulting from a faulty memory for the statement. The presentation of the five lists was preceded by a practice trial of one story (see Appendix, Table A), presented at about 225 wpm. As in the previous conditions, responses and latencies (timed from the onset of the stimulus to the onset of the subjects response) were recorded.

Results

To confirm that the LT subjects were impaired relative to the RT subjects on clinical tests of verbal memory, t-tests were performed on the scores obtained immediately after presentation and after a 90-minute delay, on the Associate Learning and Logical Memory subtests of the Wechsler Memory Scale (Wechsler, 1945). Patients in the LT group obtained significantly poorer scores than patients in the RT group on three of the tests of verbal memory, including immediate recall of the short prose passages (t (1,20) = 9.33, $p < .01$), immediate recall of the paired-associate words(t (1,20) = 8.82, $p < .01$), and delayed recall of the paired associate words (t (1,20) = 7.27, $p < .01$). There was no difference between groups on delayed free recall of the short prose passages (t (1,21) = 3.22, $p > .05$).

The dependent variables that were measured in the three experimental tasks were the number of errors made and the response times. Two or three-way analyses of variance were performed, with groups as the between-subjects variable and rate of presentation as a repeated-measures variable in the sentence-plausibility-judgement and story-memory tasks. In all three tasks, the type of stimulus (word or nonword, plausible or implausible sentence, and true or false statement) was also taken as a within-subjects factor. To obtain response times, it was necessary to subtract the amount of time required to play the stimulus from the computer-measured response latency, because response times had been measured from the onset of the stimulus. Only the data for correct responses were included in the response-time analyses, and the response-time data were transformed logarithmically to achieve greater homogeneity of variance. The performance of the one patient (from the RT group) in whom removal included part of Heschl's gyri appeared very similar to the performance of

the other RT subjects, and therefore his data were included in all analyses. All post-hoc pairwise comparisons were carried out using the Tukey test to maintain the familywise type I error rate at α =.05.

Lexical Decision Task

Errors. A two-way analysis of variance with group as the between-subjects variable and stimulus type (word or nonword) as the within-subjects variable was performed. There was no significant group-by-type interaction, but there was a main effect of group, F (2,32) = 4.64, $p < .05$, and of type of stimulus, F (1,32) = 27.69, $p < .005$. Post-hoc comparisons revealed that the LT group made significantly more errors than the NC group, $Q(1,23) = 4.28$, $p < .01$, and that all groups made more errors with the nonwords than with the words, $Q(1,35) = 7.49$, $p < .01$. These results are displayed in Figure 2.

Response times. The two-way analysis of variance resulted in no significant group differences or interaction effects. There was, however, a significant main effect of stimulus type (F (1,32) = 14.24, $p < .005$),with all groups slower at judging nonwords than at judging words ($Q(1,35) = 5.75$, $p < .01$). The mean log response time for judging words was 2.91 (se = .01), whereas that for judging nonwords was 3.00 (se = .01).

Sentence-Plausibility-Judgement Task

Errors. A three-way analysis of variance was performed on the sentence-plausibility data, with group as the between-subjects factor and rate of presentation and sentence type (plausible or implausible) as the within-subjects factors. This analysis revealed only a significant rate-by-sentence-type interaction, F (4, 128) = 3.27, $p< .05$. Although there was no effect of

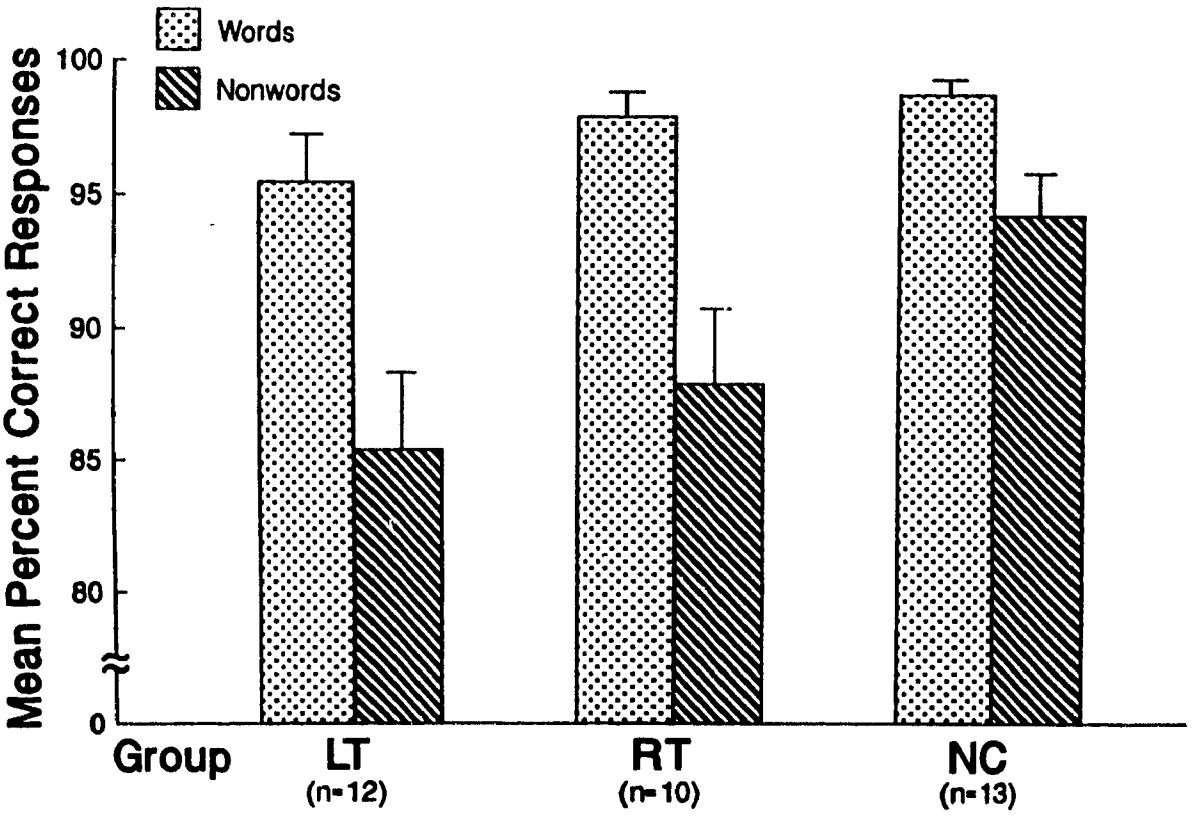

Figure 2. Lexical decisions: The percentage of words and nonwords correctly identified by subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups, respectively.

rate on comprehension of the plausible sentences (see Figure 3), there was an effect of rate on the comprehension of the implausible sentences, F (4, 128) = 3.89, p< .01, with all groups making significantly more errors at 325 wpm than at 275 wpm, Q(1,35) = 5.35, p<.01, see Figure 4. There was also an effect of sentence-type on the number of errors made at 225 wpm and at 275 wpm. At 225 wpm, more errors were made on implausible sentences, F (1, 32) = 9.05, p< .01, whereas at 275 wpm, more errors were made on the plausible sentences, F (1, 32) = 5.54, p< .05.

Response times. The three-way analysis of variance revealed a significant rate-by-type interaction, F (4, 128) = 4.48, p<.005, and a significant main effect of group, F (2, 32) = 3.82, p<.05. An analysis of the simple effects revealed a significant effect of rate on response time for both plausible, F (4, 128) =4.86, p<.005, and implausible, F (4, 128) = 13.88, p<.001, sentences. There were no significant trend components to the effect of rate on the comprehension of plausible sentences, but response times were significantly faster at 225 wpm than at either 175 wpm or 325 wpm (175 wpm vs 225 wpm: Q(1,35) = 4.72, p<.05: 225 wpm vs 325 wpm: Q(1,35) = 5.91, p<.01), see Figure 5. There was a signficant quadratic component to the effect of rate on response time for the implausible sentences, F (9, 128) = 5.657, p<.001, as portrayed in Figure 6. In addition, at the slowest speed (125 wpm), all groups were slower at judging implausible sentences than they were at judging plausible sentences, F (1, 32) = 30.37, p<.001. Post-hoc comparisons, investigating the main effect of group, demonstrated that the NC subjects were significantly faster than the RT subjects across all rates of presentation and both types of sentence, Q(1,115) = 3.81, p<.01.

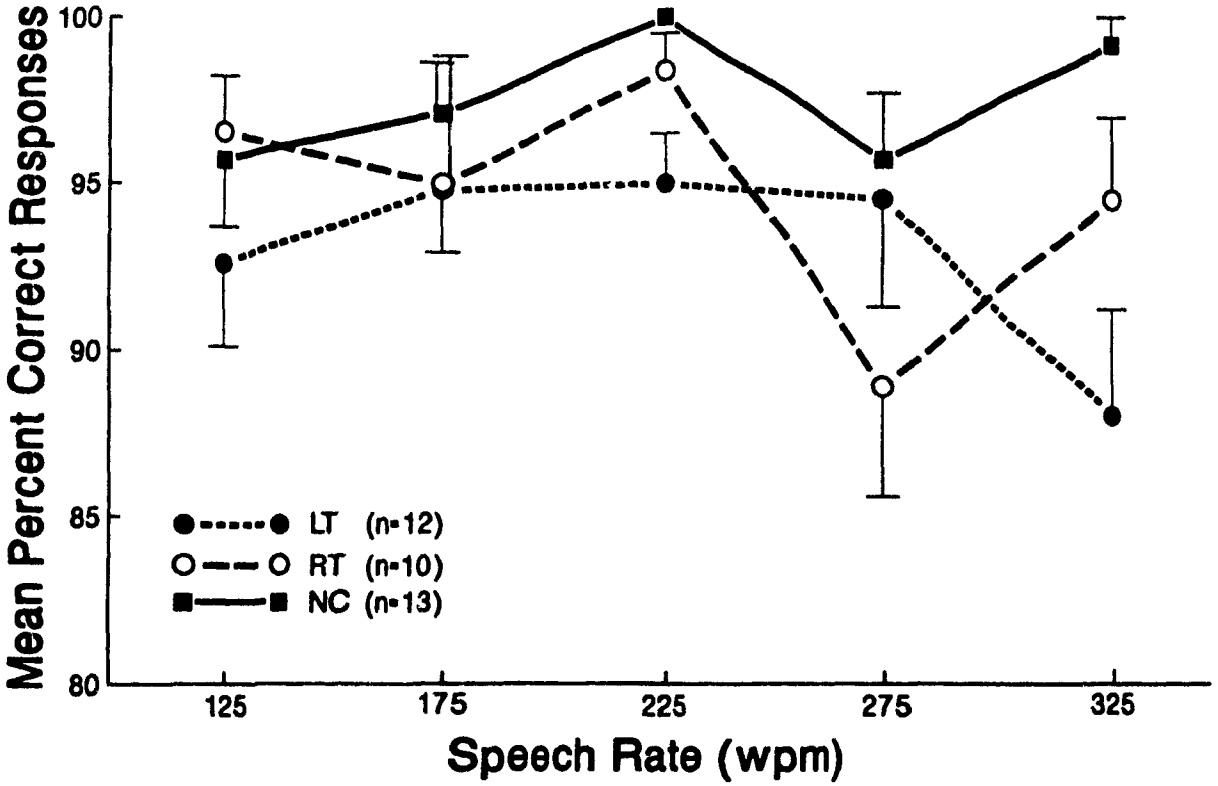

Figure 3. Sentence-plausibility judgements: Mean percentage of plausible sentences correctly identified, as a function of speech rate, for subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups.

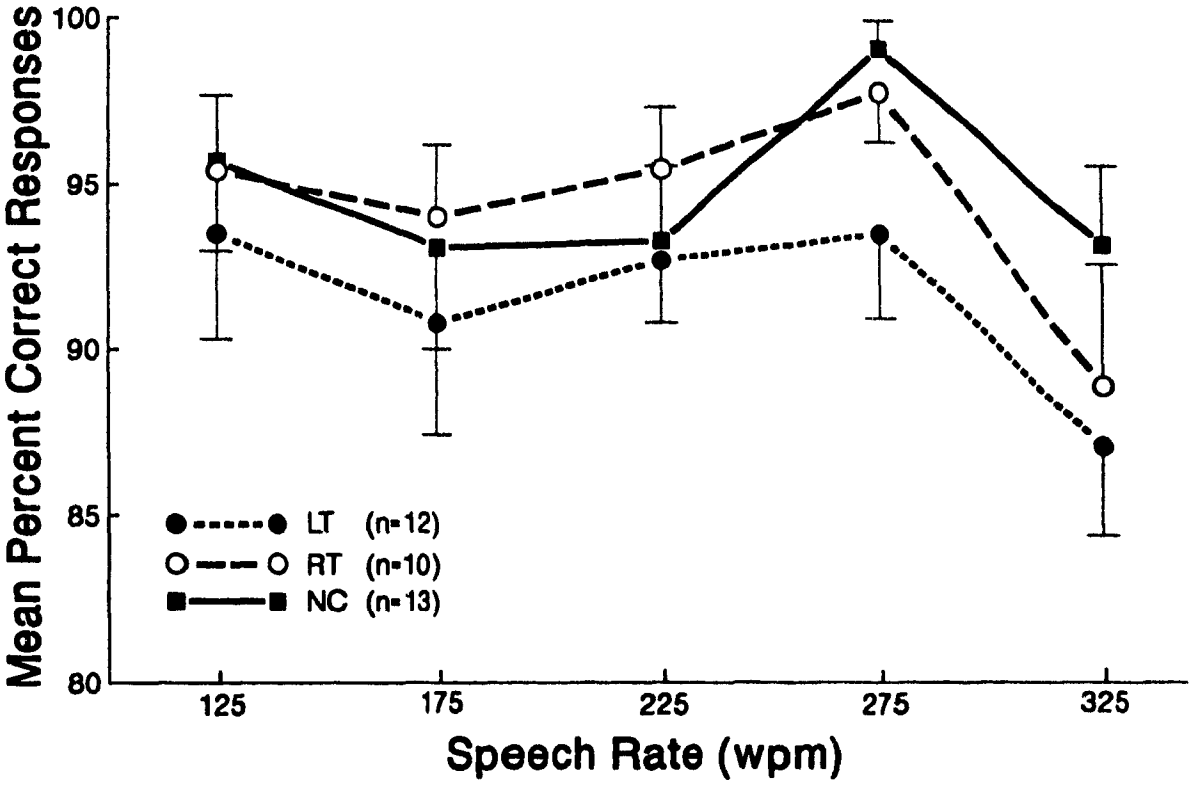

Figure 4. Sentence-plausibility judgements: Mean percentage of implausible sentences correctly identified, as a function of speech rate, for subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups.

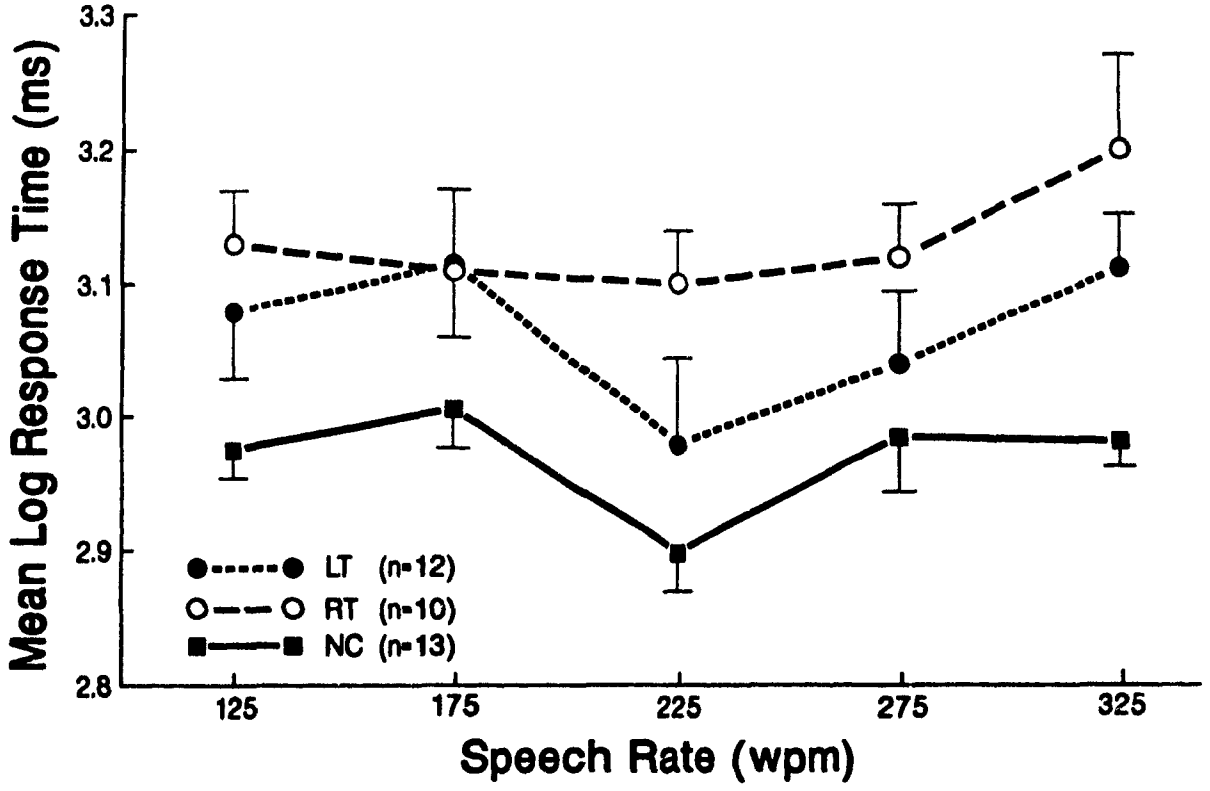

Figure 5. Sentence-plausibility judgements: Mean logarithmic response latency for the correctly identified plausible sentences, as a function of speech rate, for subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups.

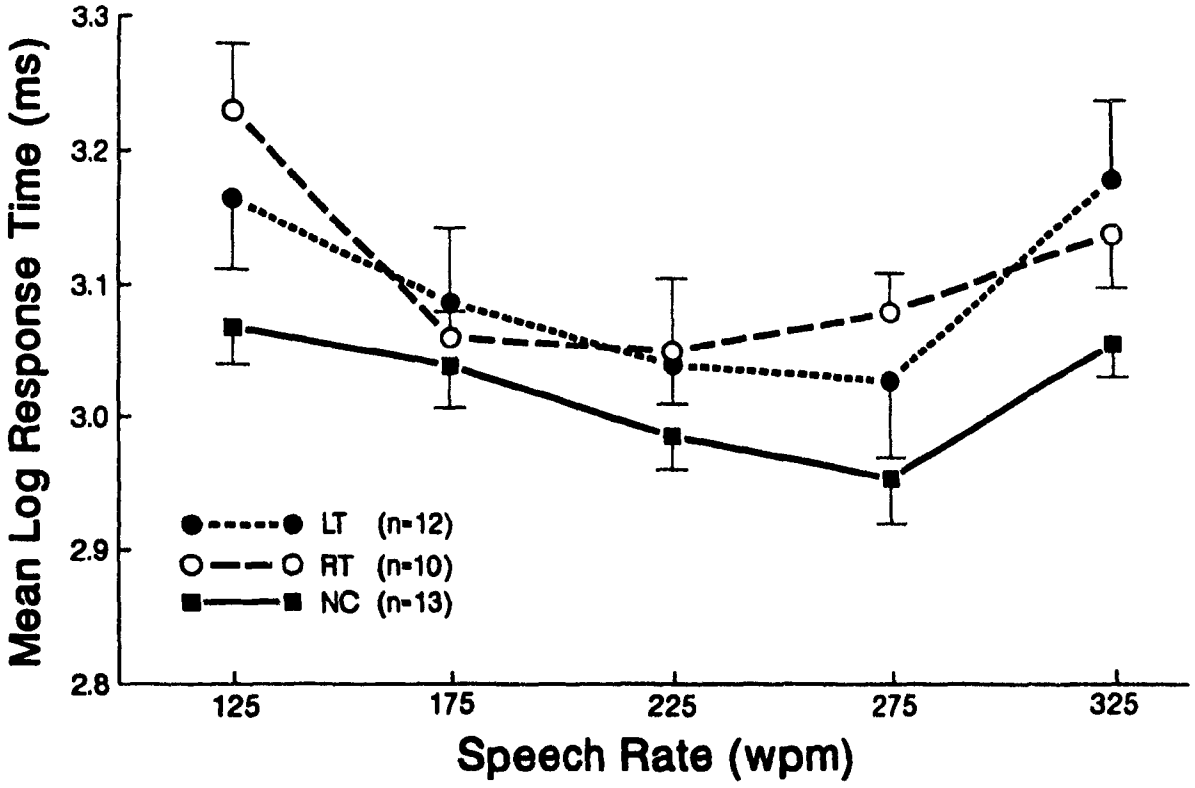

Figure 6. Sentence-plausibility judgements: Mean logarithmic response latency for the correctly identified implausible sentences, as a function of speech rate, for subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups.

Story-Memory Task

Errors. A three-way analysis of variance was performed on the data, with groups as the between-subjects factor and rate of presentation and type of statement (true or false) as the within-subjects factors. This analysis revealed a significant rate-by-type interaction, F (4, 128) = 8.69, $p < .005$, as well as a significant main effect of group, F (2, 32) = 6.39, $p < .005$.

An analysis of the simple effects and post-hoc comparisons showed that whereas there was no significant effect of rate of presentation on the number of errors made among the true statements (see Figure 7), there was a significant effect of rate on errors made among the false statements, F (4, 128) = 14.17, $p<.001$), and an analysis of trend revealed a significant linear component to this effect, F (9, 128) = 5.32, $p < .001$, with more errors being made as the speed increased (see Figure 8). In addition, at the fastest speech rate (325 wpm) all groups made more errors on the false statements than they did on the true ones, F (1, 32) = 23.64, $p<.005$. Post-hoc comparisons investigating the main effect of group revealed that normal control subjects made significantly fewer errors than did patients in the LT group, irrespective of the rate of presentation or the type of statement, $Q(1,115) = 45.52$, $p<.01$.

Response times. The three-way analysis of variance resulted in no significant group differences or interaction effects, but there was a significant main effect of rate, F (4, 128) = 53.92, $p < .001$. Post-hoc trend analysis revealed that there were significant linear, F (4, 128) = 47.56, $p<.001$, and quadratic, F (4, 128) = 4.82, $p<.005$, components to this effect, with response time declining sharply as rate of presentation increased from 125 wpm to 175 wpm, and then declining more gradually as response time increased from 175 wpm to 325 wpm (see Figure 9).

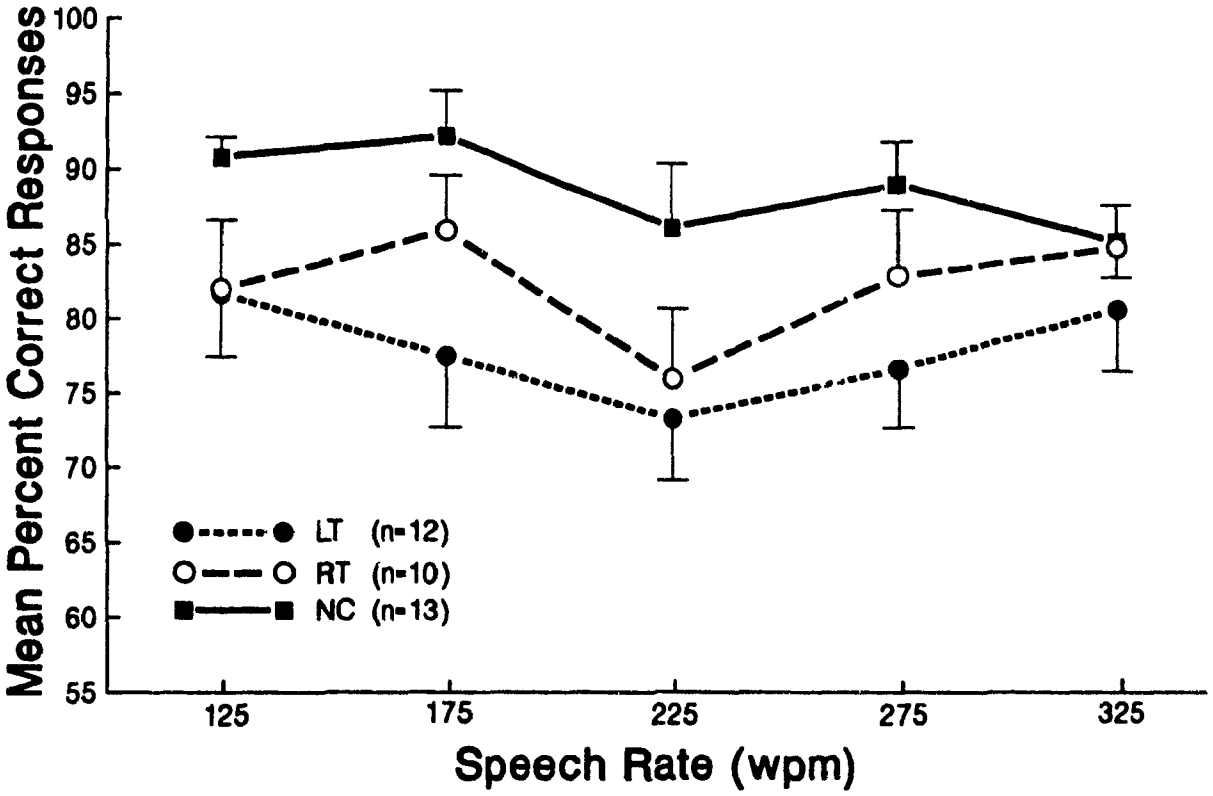

Figure 7. Story recall: Mean percentage of true statements about stories correctly identified, as a function of speech rate, for subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups.

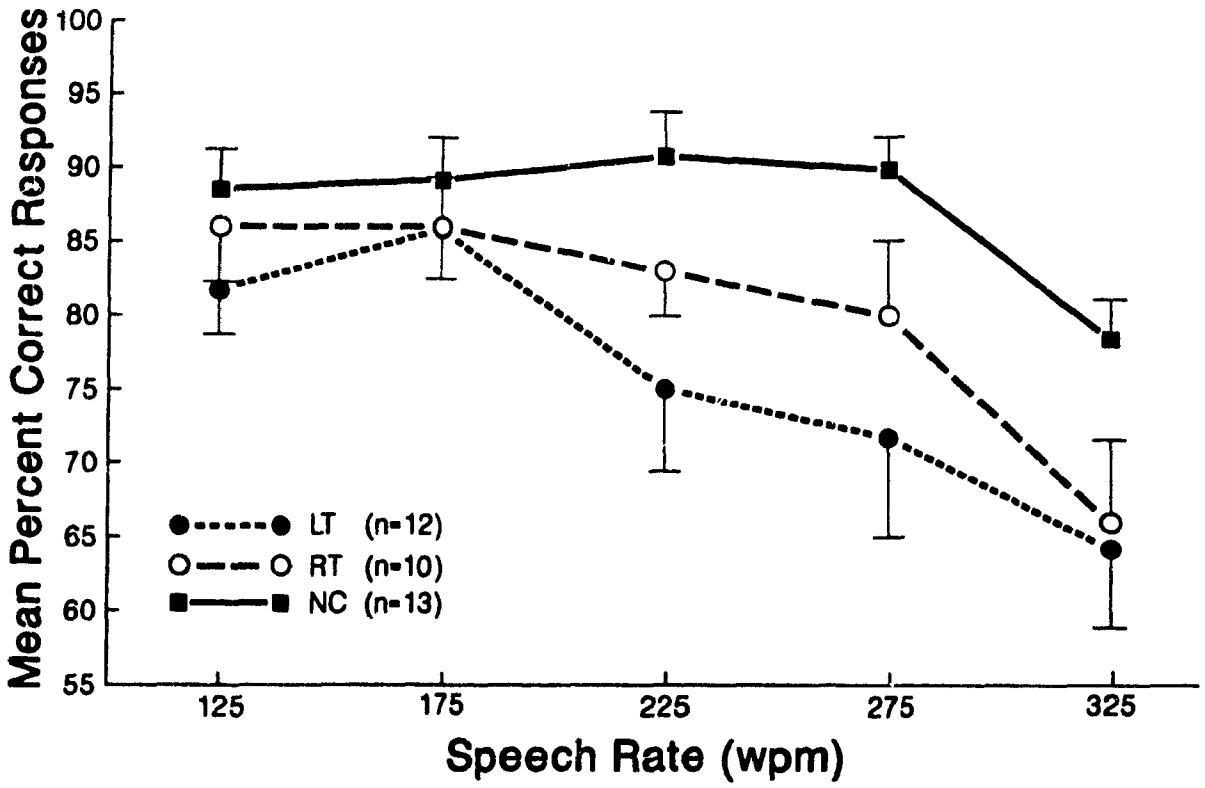

Figure 8. Story recall: Mean percentage of false statements about stories correctly identified, as a function of speech rate, for subjects in the left temporal-lobe (LT), right temporal-lobe (RT) and normal control (NC) groups.

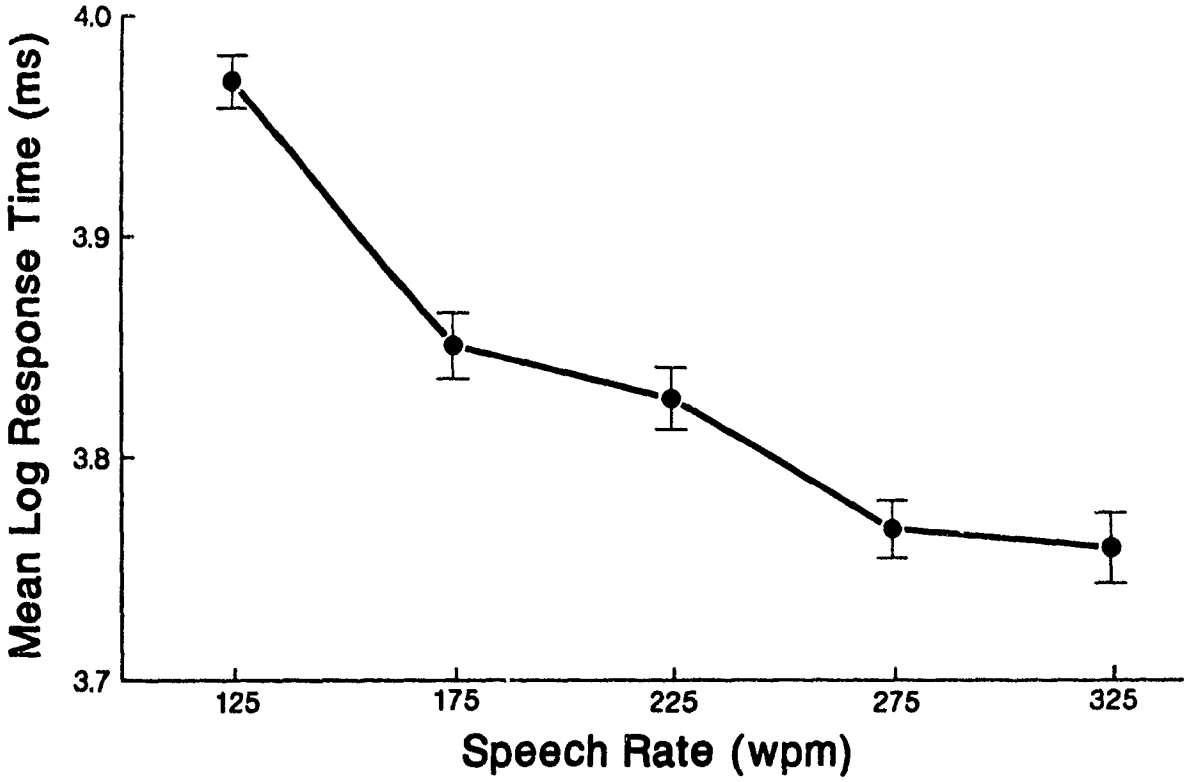

Figure 9. Story recall: Mean logarithmic response latency for correctly identified statements about stories, for all subject groups combined, as a function of speech rate.

Analysis of the effect of statement difficulty. In order to investigate the effect of the difficulty of the statements upon group differences and group-by-speech-rate interactions, a median-split analysis was performed, in which half of the statements of each type at each speed were classified as 'easy' and half as 'difficult' by ranking the statements within each speech-rate-stimulus-type condition according to the number of people who answered each statement incorrectly. The classification of each statement ('E' for 'easy' and 'D' for 'difficult') is given in Table D of the Appendix. A four-factor ANOVA was then conducted, with group as the between-subjects variable, and stimulus type, speech rate, and statement difficulty as the within-subjects variables. There was no four-way interaction, F (8, 128) = 0.75, p >.05, and there were no three-way interactions, F (4, 128) ≤ 1.83, p >.05. There was, however, in addition to the effects discussed in the preceding Errors section, a significant interaction between speech rate and difficulty, with a significant effect of speech rate on errors on the 'difficult' statements, but not on the 'easy' statements. This effect was found to be attributable the fact that, among the 'difficult' statements, significantly more errors were made at 325 wpm than at 175 wpm, $Q(1,115) = 5.54$, $p<.01$. Of course, significantly more errors were made on the 'difficult' statements than on the 'easy' statements at all speeds, F (1,32) ≥ 1.83, p <.001.

The Effect of Extent of Hippocampal Excision.

All patients were classified as having either a small (0 to 1.5 cm) or large (more than 1.5 cm) hippocampal resection. Of the patients in the LT group, 6 had small removals, and 6 had large removals, whereas 3 of the patients in the RT group had small removals, and 7 had large removals. All error and response-time analyses were repeated with extent of removal as a between-subjects variable, and no significant differences in performance

between patients who had small hippocampal excisions and those who had large ones were found.

Discussion

The results of this experiment do not support the hypothesis that left anterior temporal lobectomy slows the rate at which speech can be processed. If the impairment in verbal memory demonstrated by patients with lesions of the left temporal lobe were in part attributable to slow processing of spoken language, then one would expect that, relative to the performance of normal subjects and patients with excisions from the right temporal lobe, comprehension of sentences and stories by such patients would have been disproportionately affected by increasing the speech rate. Contrary to this hypothesis, no group-by-rate-of-presentation interaction was found in the number of errors made on either the sentence-plausibility-judgement task or the story-memory task. Furthermore, no difference between the LT group and the other groups in the effect of speech rate on latency to respond either to sentences or to statements about story content was obtained. These results, taken together with those of Frisk and Milner (1991) for visual presentation, make it extremely unlikely that abnormally slow processing of language contributes significantly to the poor verbal memory of patients with anterior left-temporal lesions.

The lack of any significant interactions between group and rate of presentation in this experiment cannot be attributed to an ineffective manipulation of the rates of presentation, since the number of errors committed by all groups on implausible sentences and false statements about stories increased as the rate of presentation increased. It is not clear why there was no effect of rate for either the plausible sentences or the true statements, and these findings differ from those obtained by Frisk and Milner (1991) for visual presentation; they observed that the number of

errors committed increased as the rate of presentation increased, irrespective of the plausibility of the sentences or the truth of the statements about the stories.

Although there did appear to be considerable variation in difficulty among the statements about the stories at all speeds, with some statements being answered correctly by almost everyone, it is unlikely that the lack of a differential effect of rate on the number of errors committed by LT subjects is attributable to the use of materials that were overly simple. The possibility that the performance of the LT subjects on the story task may have 'leveled out' at the two fastest rates because they were already responding at chance to all challenging items is unlikely, because the analysis of subjects' performance on 'easy' and 'difficult' statements revealed no group-by-speech-rate-by-difficulty interaction. There was, however, a significant effect of speech rate on the number of errors committed on 'difficult' statements but not on 'easy' ones, indicating that statement difficulty did have some differential effect on the performance of all groups.

The LT group did commit more errors than the NC group when judging the correctness of both true and false statements about stories, at all speech rates. This finding is consistent with the poor performance of these patients on clinical tests of immediate verbal learning and recall. Frisk and Milner (1991) also observed that their LT subjects made more errors than NC subjects when judging the truth of statements about stories, and the converging results of the two studies, showing that patients with left temporal lesions are poor at retaining short prose passages that they have just heard or read, further illustrate the impaired immediate recall of verbal

material already established for such patients (Milner, 1958; Milner 1967). The fact that the LT group did not make more errors than other groups in the sentence-plausibility-judgement task makes it unlikely that their impairment on the stories was owing to a failure to comprehend the individual sentences. Instead, this deficit is probably the result of a memory impairment demonstrable when the information load exceeds the capacity of immediate memory.

The finding that the latencies to respond to both types of story statements by all groups shortened as the rate of presentation increased is different from the results for visual presentation. In the present experiment, response times were slower for material presented at an average rate (175 wpm) than for material presented at fast rates. In seeming contrast, Frisk and Milner (1991) found that subjects responded most quickly when the story preceding the statements was presented at the rate at which they were used to receiving it (normal reading rate; 5 wps). Given the differences in the perception of spoken and written language, there is no particular reason to expect a correspondence on this point, even though attempts were made in both studies to include 'slow', 'fast' and 'normal' rates of presentation.

The results of analyses on error data and on response-time data obtained in the sentence-plausibility-judgement task are not straightforward. The effect of sentence type on the number of errors made is difficult to understand, in that at the middle speed (225 wpm) there were more errors made on the implausible sentences, whereas at 275 wpm, more errors were made on the plausible sentences. It is possible that this result is an artefact of the particular sentences presented at these rates, but an inspection of the

stimulus material (see Appendix C, Tables C-4 and C-5) does not reveal any conspicuous differences in either the plausible sentences or the implausible sentences presented at these rates, relative to the material used at other speeds.

Frisk and Milner (1991) found that latency to judge sentence plausibility lengthened as the rate of presentation increased, with the shortest response times at a presentation rate (2 wps) slower than that of normal reading (5 wps). This does not appear to be the case in the current experiment, since subjects responded fastest to the implausible sentences when they were presented at c ıe of the intermediate rates (around 225 wpm), faster than normal speech. As mentioned earlier, there is no reason to expect that the results for the two experiments would be similar in this respect, even though 'slow', 'normal' and 'fast' rates of presentation were employed in both studies.

The response times of the RT patients when judging the acceptability of sentences were significantly longer than those of the NC subjects, across all speech rates and for both plausible and implausible sentences. Seven of the 10 RT subjects had large hippocampal removals. Frisk and Milner (1991) also found that patients with right temporal-lobe excisions that included a large portion of the hippocampal formation were slower than NC subjects when making lexical decisions about words, and when judging the plausibility of implausible sentences presented at a moderate rate. Although the longer response latency of the RT group relative to other subject groups was not obtained for the same tasks in the two experiments, the fact that it was evident in both studies would argue against it being spurious. Although Frisk and Milner (1991) suggested that the slowed response time of the RT

subjects was secondary to the more general visual-perceptual deficit associated with such lesions (Kimura, 1963; Lansdell, 1968; Meier & French, 1965; Milner, 1958), the results of the present investigation argue against this explanation, since a similar deficit was found in the auditory modality. It is also unlikely that the longer response latencies are simply due to an impairment in motor control caused by the surgery: the effect was obtained not only for the hand contralateral to the lesion, but also for the ipsilateral one (that is, for judgements of both plausibility and implausibility).

The results of the lexical-decision task are clear. There were more errors made when judging the legitimacy of nonwords than when judging the legitimacy of words. These findings seem to agree with Frisk and Milner (1991), although they analysed the results for words and nonwords separately, and therefore could not compare the two directly. In an early lexical-decision experiment in normal subjects using visual presentation (Rubenstein, Garfield, & Millikan, 1970), however, the error rates for words and nonwords appeared identical. The subjects in their study were all university undergraduates, and hence more educated, on average, than the participants in the studies at the MNI. It is possible that they were consequently more confident about labeling nonwords.

Response latencies were longer when subjects were judging the legitimacy of nonwords than when they were judging the legitimacy of words.This finding is consistent with those of Frisk and Milner (1991), and Rubenstein, Garfield, and Millikan, 1970, and, in fact, seems to be a robust and general property of all "same"-"different" judgements about codable stimuli (Bindra, Donderi & Nashisato, 1968; Farell, 1985).

It is interesting that the LT group made more errors that the NC group in judging the legitimacy of both words and nonwords. Frisk and Milner (1991) found no differences between their LT group and other groups in the performance of a lexical decision task in which the stimuli were presented visually. The finding that the LT group does make more errors than the NC group when the stimuli are presented aurally lends further support to the hypotheses of Rains (1981), Read (1981a) and Milner (1985), who have suggested that the left anterior temporal neocortex plays a special role in auditory processing. From the present study, it appears that left anterior temporal lobectomy renders phonemic sounds less able to evoke the meaning of words, and this result is similar to that of Zatorre (1989), who found that patients with such lesions appeared to have difficulty retrieving the lyrics of distorted familiar melodies. Furthermore, the results of the two lexical-decision studies, taken together, add further support to dual route theories of lexical access (Baron, 1983; Coltheart, 1978), by demonstrating that the identification of a printed word does not seem to require the same processing pathways as the identification of a spoken one. Of course, concluding that there is a dissociation between auditory and visual processing on the basis of these two experiments is not entirely legitimate. The evidence must be strengthened by performing a study in which patients with unilateral anterior temporal lobectomies and normal control subjects perform lexical-decision tasks in both modalities, so that comparisons of performance between modalities can be made within subjects.

The extent of hippocampal excision did not appear to have any effect on the performance by patients in either of the temporal-lobe groups, on any task, and this is consistent with the hypothesis that these tasks tap

functions subserved largely by the neocortex of the left hemisphere. This hypothesis can be further investigated by testing patients in whom the neocortex has been spared. The procedure of selective amygdalo-hippocampectomy (Wieser and Yasargil, 1987) is beginning to be employed at the Montreal Neurological Hospital as an alternative to anterior temporal lobectomy for the treatment for focal epilepsy, and by testing patients with such removals on the tasks of this study, and comparing their performance to that of patients with more traditional resections, it will be possible to examine more directly the relative contributions of neocortex and mesial structures to the processing of speech.

Although manipulations of the rate of presentation of language (both auditory and visual) do not affect immediate recall by patients with left temporal-lobe excisions any differently than they do recall by the other groups studied, the question of the effects of these manipulations on delayed recall has yet to be addressed. It would be interesting to perform a slightly modified version of the present experiment, in which, after a delay of several hours, the patient must recognize elements from the stories. It is possible that the rate at which verbal material is presented may affect the strength of the encoded representation, and hence may affect the rapidity with which an item is forgotten. This effect cannot be examined if only immediate recall is assessed. Moreover, a delayed-recall task is a more accurate way to mimic the mnemonic demands of real life than is an immediate-recall task.

This work makes two major contributions. First, the results of this study raise interesting questions about the role of the left anterior temporal region in auditory processing. The finding that patients with left temporal-

lobe excisions are poorer than normal subjects and patients with right temporal-lobe lesions at judging the legitimacy of words and nonwords when the stimuli are presented aurally, but not visually, lends support to the notion that this area is somehow involved in representing the sounds of language (Rains, 1981; Read, 1981a; Milner, 1985). Finally, the recall of stories by LT patients was not disproportionately impaired relative to that by NC subjects and RT patients as the speech rate increased, and this result, taken together with that obtained by Frisk and Milner (1991), makes it very unlikely that the poor verbal memory of patients with left anterior temporal lobectomies is partly attributable to abnormally slow processing of language.

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APPENDIX

Table A

Practice Stimuli

Lexical-Decision Task

Words	Nonwords
sold	teels
threw	slove

Sentence-Plausiblity-Judgement Task

1. When someone cracks a joke you frown. (F)

2. Diamonds are precious stones often put in rings. (T)

3. One writes easily with a completely empty pen. (F)

4. Reading is learned in the early elementary grades. (T)

Story-Memory Task

Tom and Ann love to cook. Tom is very fond of seafood and vegetables, and so uses these in many of his recipes. Ann loves to bake, and makes lovely muffins. They have many friends and often invite them to dinner.

Ann and Tom have lots of friends (T).

Tom loves to bake (F).

Ann bakes very nice cookies (F).

Tom doesn't use vegetables in his recipes (F).

Table B

Stimuli for Lexical-Decision Task

Words	Nonwords
tree	loof
store	wold
safe	grop
neck	slatch
desk	flain
wind	stip
sight	slair
camp	chape
block	flave
grew	lesk
watch	taise
runs	sprew
swung	treak
loan	plaw
feels	loast
sell	melp
broad	skime
slow	nare
wild	fent
wood	slint
rare	sloss
swift	duge
torn	fots
false	neep

Table C-1

Stimuli presented at 125 wpm in Sentence-Plausibility-Judgement Task

1. The teacher stood on the stool to reach the top shelf. (T)
2. She loved watching soap operas at the movies. (F)
3. The blackboards in the classroom were at the front of the room. (T)
4. It is faster to take a train than to travel by bicycle. (T)
5. He stood on a book to repair the flagpole. (F)
6. Kim told the children to be quiet because Karen was sleeping. (T)
7. John always ate his soup with a fork. (F)
8. Jack wore a three-piece pin-stripe suit that matched his teeth. (F)
9. The brook bubbled slowly up the hill. (F)
10. The flag hung limply while the pole swayed in the breeze. (F)
11. She doesn't like green vegetables so she didn't eat her mashed potatoes. (F)
12. The autumn leaves, in brilliant colours, fell softly to the forest floor. (T)
13. The public library is a popular place to find books. (T)
14. Little girls usually like playing with dolls. (T)
15. The birthday cake was served with vanilla ice cream. (T)
16. Halfway down the mountain he noticed he had put his skis on upside down. (F)
17. The moon often shines more brightly than the sun. (F)
18. One doesn't usually take baths with clothes on. (T)

Table C-2

Stimuli presented at 175 wpm in Sentence-Plausibility-Judgement Task

1. Most children are depressed on the first day of vacation. (F)
2. Winter is the most popular season for camping. (F)
3. The little girl had blue stains on her dress from playing in the grass. (F)
4. Two of his shoes were blue, and the other one was black. (F) 12/13
5. The little girl was given a doll for her birthday. (T)
6. Many students were nervous about writing the test. (T)
7. The child threw a ball through the window. (T)
8. Sally loves flowers, particularly when they are sprinkled over cereal. (F)
9. She decided to take a bus instead of a taxi so she could save money. (T)
10. The child cried when she fell off her bicycle. (T)
11. The dirty clothes were washed on laundry day. (T)
12. The cat ran under the bed and hid from the mouse. (F)
13. The ice cream was warmer than the soup. (F)
14. She took piano lessons in order to learn how to play the piano. (T)
15. Each morning he stepped into the shower holding two pieces of toast. (F)
16. Playing the guitar is a popular pastime for young dogs. (F)
17. One often sees horses, cows, pigs, and camels on a farm. (F)
18. Deep red rosebuds covered the rosebush by the house last spring. (T)

Table C-3

Stimuli presented at 225 wpm in Sentence-Plausibility-Judgement Task

1. The gas station sells cigarettes and candy as well as gas. (T)
2. The little boy's tie was spotted by invisible ink. (F)
3. Jane took a geography class to learn how to fix her car. (F)
4. The maple tree leaves turned red in the fall. (T)
5. While snow fell softly outside a fire crackled merrily in the garage. (F)
6. The man likes to drink coffee with his breakfast. (T)
7. Before he goes to bed, Joe brushes his teeth with a comb. (F)
8. I travel back and forth to work in my car. (T)
9. The man couln't write because he had no legs. (F)
10. Each morning she made the bed, scrubbed the floor, and vacuumed the cat. (F)
11. They loved to skate on the lake in winter. (T)
12. The policeman held up his hand to stop the traffic. (T)
13. People who love to eat sweet foods usually like to drink vinegar. (F)
14. The man put on thick wool socks because his feet were cold. (T)
15. He picked up a hammer from the basement workbench. (T)
16. After the furnace broke down the house became colder. (T)
17. Bill raised his own chickens because he loved fresh cheese. (F)
18. He put on his running shoes to go jogging. (T)

Table C-4

Stimuli presented at 275 wpm in Sentence-Plausibility-Judgement Task

1. He could hear music playing softly from the refrigerator. (F)
2. Sky diving is a sport popular with grandparents. (F)
3. The woman was so tired, she fell asleep on the livingroom sofa. (T)
4. He took a present to the birthday party. (T)
5. He jumped into his car and drove off down the river. (F)
6. The children's drinking fountain was lower than the one for adults. (T)
7. She spread the letter thickly with peanut butter and ate it. (F)
8. The office staff was relieved when their lazy coworker quit. (T)
9. The windows of the room were located in the floor. (F)
10. The farmer used a tractor to plow his fields. (T)
11. She walked to the kitchen for a glass of cold orange juice. (T)
12. She went to camp during her summer holidays. (T)
13. The shirt was striped but one of its ears was missing. (F)
14. They put ice in the oven to make sure it was crisp. (F)
15. January is one of the coldest months of the summer. (F)
16. It was more fun water-skiing when the weather was warm. (T)
17. Alan read a book on insects to learn more about whales. (F)
18. They water their flowerbed when the flowers start wilting. (T)

Table C-5

Stimuli presented at 325 wpm in Sentence-Plausibility-Judgement Task

1. Many people like their coffee with a teaspoonful of salt. (F)
2. Kim's favourite hobbies are swimming, sailing and crying. (F)
3. Instead of walking, he drove to work so he would not be late. (T)
4. Many people don't go to work on weekends. (T)
5. He stood on a book to repair the flagpole. (F)
6. The children were excited about visiting the zoo. (T)
7. Our little grey kitten just died yesterday of extreme old age. (F)
8. The railway tracks were marked as a dangerous place to play. (T)
9. Both front wheels of his bicycle are crooked. (F)
10. The hunter fired his rifle at the running deer. (T)
11. The moving men put the stove in the kitchen. (T)
12. The glass slipped from Larry's hand and fell to the floor (T)
13. It is most enjoyable to play baseball when it is snowing. (F)
14. Jane turned on a light because it was too dark to see. (T)
15. His office was located three hundred feet beneath sea level. (F)
16. He turned off the refrigerator because he smelled something burning (F)
17. He preferred playing ice hockey in his bare feet. (F)
18. He learned to add and subtract in math class. (T)

Table D-1

Stimuli presented at 125 wpm in Story-Memory Task

1. Mrs. Green went to answer the doorbell. She thought it was the deliveryman. When she opened the door she was surprised. It was the mailman. He had a letter for her.

   She went to answer the telephone. (F-E)

   Mrs. Green was surprised to see the mailman. (T-E)

   Mrs. Green was surprised when she opened the door. (T-E)

   The mailman had a package for her. (F-D)

2. It was the twins' birthday. Jeffrey rushed to the store to buy some gifts for his brothers, and a birthday cake. He didn't realize Erica had already baked one. When he arrived home, he was very surprised to find there was already one in the house.

   He didn't know Erica had baked cupcakes. (F-E)

   Jeffrey went to the store to buy Christmas gifts for the twins. (F-E)

   Jeffrey was surprised to find another cake at home (T-E)

   The twins were Jeffrey's brothers. (T-D)

3. Last Tuesday, Kim's father bought her a new dress for a birthday party the next day. Kim disobeyed her father by wearing the dress when she was playing outside Tuesday afternoon. She tore the dress, and so had to wear an old dress to the party. Kim was ashamed of her behaviour.

   Kim went to a Christmas party (F-E).

   Kim's father did not want her to wear the dress Tuesday afternoon (T-D).

   The party was on Wednesday (T-D).

Kim stained her dress while playing outside (F-D).

4. The auction began at ten A.M. Although there was a large crowd, the bidding started slowly. Many of the chairs and tables sold at very low prices. The Davidsons waited anxiously until the cabinet they wanted was brought forward. They joined in the bidding, hoping they would be able to buy it.

   The auction took place in the afternoon. (F-D)

   The Davidsons were worried they wouldn't be able to buy the cabinet. (T-D)

   Few people were present when the auction began, so the bidding started slowly. (F-D)

   Many of the pieces of furniture were inexpensive. (T-D)

5. Every Friday morning, Mrs. Brown washes her car. It is a 10-year-old Cadillac. She has always taken good care of her car, and it has served her well. Last Friday as she was cleaning it, she was upset to discover rust on the doors and on the trunk. Regretfully, she decided she must sell her car and get a new one.

   Mrs. Brown washes her car once a month (F-E)

   Mrs. Brown's car is a Cadillac (T-E).

   Mrs. Brown was eager to sell her car (F-D).

   Mrs. Brown decided to sell because she discovered rust. (T-E).

Table D-2

Stimuli presented at 175 wpm in Story-Memory Task

1. George and Ann like to play cards. George often wins when they play Rummy. Ann is a good player too. She tends to beat George at Cribbage. When she does, George gets angry.

   George doesn't mind when Ann wins at cards. (F-E)

   Ann is not good at playing cards. (F-D)

   Ann generally wins the Cribbage games. (T-D)

   Ann likes to play Cribbage. (T-E)

2. It was a rainy, foggy day. Pete thought it was a perfect day for travelling. He climbed on the train right after breakfast. He found a seat on the aisle, and opened his new novel. It was a thick one, just right for a long trip.

   Pete liked to travel on cloudy days. (T-D)

   Pete began his train ride just before supper. (F-E)

   Pete had brought a large book with him. (T-E)

   Pete wasn't travelling far. (F-D)

3. They were preparing for their expedition. Jack was in charge of organizing the meals while Alex took care of the equipment. The canoe stood bobbing at the dock. They loaded their gear quickly and pushed off. Both boys were anxious to reach the island and pitch the tent before dark.

   The dinghy stood waiting at the pier. (F-E)

   The boys were going camping on an island. (T-D)

The boys were getting ready for their trip. (T-E)

They had to sail to their campsite. (F-D)

4. Beth had many pigeons in her garden. They ate all the seeds, so that nothing ever grew except weeds. The pigeons never bothered Beth's neighbour. Beth started throwing crumbs over the fence into her neighbour's yard. Soon Beth's garden was growing nicely and there was nothing in her neighbour's except weeds.

   The sparrows ate crumbs in Beth's garden. (F-E)

   Beth had lots of robins in her yard. (F-E)

   Beth threw crumbs over the fence into the adjoining yard. (T-D)

   Beth garden grew well after she threw crumbs over the fence. (T-E)

5. When the evenings began to get cool, the lady next door brought all of her plants inside. It took her three hours to prune them and take cuttings for new plants. She placed the new slips in water, hoping that roots would develop. Most of the plants were geraniums and begonias and she was hoping she would have many new flowering plants for the spring.

   Almost all of the plants were geraniums and chrysanthemums. (F-D)

   The woman pruned all of her plants one evening while out in her garden. (F-D)

   Because of the cold weather, the woman next door took all of her plants inside for the winter. (T-D)

   The lady pruned the geraniums and put the cuttings into water to take root. (T-E)

Table D-3

Stimuli presented at 225 wpm in Story-Memory Task

1. On the way to work, Mr. Smith saw a fire. All of the traffic slowed as the cars passed the fire trucks. He was worried he would be late. A soon as he could, he sped up and passed the traffic ahead of him.

   Mr. Smith saw a hold-up on the way to work. (F-D)

   Mr. Smith saw a fire while riding the bus to work. (F-E)

   Mr. Smith was afraid he wouldn't be on time. (T-E)

   Once he was past the fire trucks, he began to drive more quickly. (T-D)

2. It was the first day of class. Richard arrived at the air field early. He had always dreamt of sky diving. He could hardly wait to make his first jump. He listened intently to the instructor as he explained how to prepare a parachute.

   Richard arrived well before his lesson began. (T-E)

   It was the first day of scuba diving class. (F-D)

   Richard was impatient to make his first jump. (T-D)

   He had always wanted to learn how to parachute. (T-E)

3. Once a day Marie winds the clock over the fireplace. Her grandfather had brought it from Italy 75 years ago. It was given to him by a neighbour, in whose attic it had lain, broken, for decades. Grandfather fixed it before he came to Canada, and it has worked well ever since.

   Once a day, Marie winds the timepiece from Italy. (T-D)

   Grandfather brought a new clock to Canada. (F-E)

Grandfather repaired the clock in Canada. (F-D)

A neighbor gave the clock to Grandfather. (T-D)

4. Susan and John were busy folding the laundry. It had been hung to dry at the side of the house. Their brothers were in front playing with some garden hoses. When Susan and John came around the corner, they got caught in the crossfire. Everything they were carrying was soaked and they were furious.

   Susan and John were busy hanging out the wet clothes. (F-D)

   The wash had been hung on a clothesline at the side of the house.(T-D)

   Susan and John weren't upset that everything got wet. (F-E)

   The laundry was splashed by the hose. (T-E)

5. The morning of the annual office picnic was warm and sunny. Kathy hummed as she packed an enormous amount of food into the picnic hamper. There was cold chicken, ham, and four types of sandwiches. There wasn't any room left when she had finished packing everything. Kathy was still concerned there wouldn't be enough food to go around.

   It was overcast the day of the picnic. (F-E)

   The school picnic was an annual event. (F-D)

   Kathy had prepared a variety of food for the picnic. (T-E)

   After packing the hamper, Kathy was sure there would be enough to eat. (F-E)

Table D-4

Stimuli presented at 275 wpm in Story-Memory Task

1. David was nervous about opening night. All of the seats had been sold. It was his first public performance and the critics from the newspaper would be attending. He continued to rehearse his lines as he watched the crowd take their seats.

   The critics would be covering the performance. (T-E)

   This was David's musical debut. (F-D)

   David was anxious about the first performance of the play. (T-D)

   The crowd filled the playhouse. (T-D)

2. It was cold and cloudy when Alison and her brother went to bed. During the night, Alison woke up and heard the wind whistling fiercely. The branches of the trees clattered against the windows. In the morning she looked outside and saw that everything was covered in white.

   The branches banged against the panes of glass. (T-D)

   The rain began after the children went to sleep. (F-E)

   When the two girls went to bed, it was cold and cloudy. (F-D)

   The wind blew fiercely during the snowstorm. (T-D)

3. When Steven and his girlfriend left for the races the sky was filled with grey clouds. It started to rain halfway through the afternoon. The races ended early. None of the horses could run in the mud. So Steven and his girlfriend got in the car and drove home.

   Midway through the morning it started to rain. (F-D)

   Steven and his girlfriend went to the car races. (F-E)

It was overcast when Steven and his girlfriend left for the races. (T-D)

The races ended early because of the weather. (T-E)

4. Jimmy's mother asked him to go to the store to buy milk and bread. Jimmy went on his new skateboard. On the way home, he dropped the milk. The container broke, spilling all the milk onto the pavement. When he told his mother, she did not become as angry as he had expected.

   Jimmy went to the store on his new skateboard (T-E).

   Jimmy dropped the eggs onto the pavement (F-E).

   Jimmy told his mother that he dropped the milk(T-E).

   His mother was very angry (F-E).

5. The Christmas parade is always a big event for children. In spite of cold weather, hundreds line the streets every year to catch a glimpse. There are always many floats and clowns, but the highlight is Santa Claus in his sleigh. Many fathers hoist their children onto their shoulders so they will have a good view.

   Children are always excited about the Easter parade. (F-E)

   Fathers often hold their children in their arms so they can see the parade. (F-D)

   The best part of the parade are the clowns. (F-D)

   Despite the cold, the Santa Claus parade draws many spectators. (T-E)

Table D-5

Stimuli presented at 325 wpm in Story-Memory Task

1. It was an early winter. Bob and Sally rushed to harvest the crops. They needed the corn and barley for their goats. Buying feed would be expensive. They were relieved when the harvest was plentiful.

   They had to hurry to gather the crops before winter. (T-E)

   Bob and Sally fed their cows wheat and barley. (F-E)

   They had to buy food for their animals. (F-E)

   They were able to harvest enough to feed their goats. (T-D)

2. The child wanted some candy. His father gave him a dollar. He ran into the store with his best friend. When he had finished choosing, he had spent most of what his father gave him. He left the store carrying a big sack full of candy.

   He entered the store with his father. (F-E)

   The bag of candy cost one dollar. (F-D)

   The little boy wanted some sweets. (T-E)

   The child's father gave the boys a dollar. (F-D)

3. Sandra likes to walk Snoopy on the beach. In the early morning the beach is usually empty, so he is allowed to run about freely. In the afternoon though, there are always joggers training, and children building sandcastles. At this time, Sandra keeps Snoopy on a short leash, by her side.

   Sandra enjoys exercising Snoopy in the park. (F-E)

   She doesn't always keep her dog on a leash when she walks him on the beach (T-D)

There are always many runners on the beach during the afternoon. (T-D)

Sandra keeps Snoopy on a leash during their early morning walks. (F-D)

4. Henry arranged to meet his friend at the movie last Tuesday night. He thought it was playing at the theatre on Grey Avenue. His friend was waiting at the Green Cinema. When Henry realized his mistake, he took a taxi to the proper theatre. In spite of this, he was twenty minutes late.

   He drove his car to the correct theatre after realizing his error. (F-E)

   Henry's friend was waiting for him at the Green movie theatre. (T-D)

   Henry and his friend had made plans to meet last Saturday night. (F-D)

   Although Henry took a taxi, he was late arriving at the theatre. (T-E)

5. The lawn was covered with leaves. Daniel walked to the tool shed to get the rake. He worked hard for an hour, clearing the front yard. As soon as he went inside, the boys from across the street came over to investigate the piled leaves. When Daniel looked outside later that day, the leaves were scattered once more.

   Fallen leaves covered the grass. (T-E)

   The boys from next door kept jumping into the leaves. (F-D)

   It took one hour to rake the front yard. (T-D)

   The boys scattered the leaves. (T-E)